

Continuous Intraoperative Monitoring of Temporal Lobe Epilepsy Surgery

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Keywords

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Abstract

Background/Aims: The monitoring of interictal epileptiform discharge rates (IEDRs) all along anterior temporal lobe resections (ATLRs) has never been reported. Here the effect of ATLR on continuous IEDR monitoring is described. **Methods:** IEDRs computed automatically during entire interventions were recorded in 34 patients (38.2%, 13/34 depth; 61.8%, 21/34 scalp electrodes only). Monitorings were invalidated when burst suppression occurred or if initial IEDRs were <5. **Results:** Monitoring was successful for 69.2% (9/13) of the patients with depth recordings and for 4.8% (1/21) of the patients with scalp recordings. Burst suppressions precluded it in 30.8% (4/13) of the depth and in 57.1% (12/21) of the scalp recordings. Initial IEDRs were <5 for 38.1% (8/21) of the scalp recordings. Significant IEDR decreases were observed in 8/10 patients with successful monitoring. These decreases started with resection of the superior temporal gyrus. IEDRs decreased further with amygdalohippocampectomy in 3/5 patients. At the 12-month follow-up, all patients with IEDR decreases remained seizure free; both patients without did not. **Conclusion:** IEDR monitoring was possible with depth, but

not with scalp electrodes. IEDR decreases started with resection of the superior temporal gyrus. A larger patient cohort is necessary to confirm the high predictive values of IEDR monitoring that could become a tool for surgery customization.

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Introduction

Anterior temporal lobe resection (ATLR) including mesial temporal structures [1] (mesial ATLR) can lead to seizure suppression in more than 70% of patients with temporal lobe epilepsy (TLE) [2–4], even in the long term [5]. Following ATLR, patients report an improvement in their quality of life [6], but nonetheless, ATLR can be sometimes associated with important cognitive declines, in particular when lesions are located in the left temporal lobe [7] or when neuropsychological performances are thought to have been normal prior to surgery [3, 8]. Neuropsychological impairments are proportional to the extension of the resection [9]. In this sense, a trade-off between benefits and risks of surgery must be made, and seizure freedom should be ensured with the smallest amount of tissue resected.

In this perspective, this work introduces a method to monitor the ongoing effect of ATLR by observing the

temporal evolution of the interictal epileptiform discharge rate (IEDR) during surgery. Interictal epileptiform discharges (IEDs) are spontaneous, short-time duration (<200 ms) abnormalities of the electroencephalogram (EEG). Even if they are supposed to result from pathological synchronized neuronal firing, this statement is still under debate [10]. In animal models, their roles are linked to either seizure prevention or facilitation [11]. The IEDR has been used as a neurophysiological marker, allowing quantifying the epileptiform activity. In deep brain stimulation [12, 13] or vagal nerve stimulation [14–18], it has been shown that IEDR reduction is correlated with seizure frequency decrease. In the domain of temporal lobe surgery, Oliveira et al. [19] intraoperatively compared IEDs before and after resection of the temporal pole and after resection of the mesial structures. They concluded that the observation of isolated discharges only, opposed to more complex epileptiform patterns, was predictive of the patients' outcome. A previous attempt to assess the predictive value of IED recorded intraoperatively was conducted by McBride et al. [20]. They reported that a persistence of 50% or more epileptiform activity after temporal lobe resection was correlated with poor outcome in 80% of the patients ($n = 5$). Nevertheless, in this study the comparisons of postresection EEGs to pre-resection EEGs were certainly biased by the use of thiopentone sodium, well known to increase epileptiform activity [21]. In an extensive review of epilepsy surgery, Rathore and Radhakrishnan [22] showed that presence or absence of IED after surgery is significantly associated with the outcome of temporal lobe resection. In this review, IEDs were treated as a binary variable (present or absent), and due to the variety of studies grouped together [23] the postoperative EEG protocols as well as IED detection were not homogeneous. These studies, based on electrocorticography, also share some technical limitations: they require the surgery to be stopped, they are intermittent, and they can be modified by the position of the cortical electrodes.

The goal of the present study was to describe how IEDRs were modified during whole ATLRs with or without mesial structure resections. They were computed continuously, every minute, all along the surgery, and automatically to guarantee reproducible marking, eliminating human EEG reviewing variability [24]. In the present study, brain activity was recorded continuously during the whole surgery, from ipsilateral hippocampal depth electrodes, contralateral mesial depth electrodes, or ipsilateral scalp electrodes, including all resection periods.

Methods

Patients

EEGs were recorded in 34 patients with pharmacoresistant TLE. Patients with any extratemporal lesion resection were excluded. Intraoperative monitoring of epileptiform discharges with IEDRs was performed in 38.2% (13/34) of cases from depth electrodes and in 61.8% (21/34) of cases from scalp electrodes.

All patients underwent a comprehensive workup, in order to determine whether they were suitable candidates for surgery. This included high-resolution brain magnetic resonance imaging (MRI), video-EEG telemetry, interictal positron emission tomography, ictal and interictal single-photon emission computerized tomography, and neuropsychological and psychiatric examination.

Additional intracranial invasive exploration could be performed because of discordant scalp EEG data collected during the noninvasive preoperative workup. Patients were implanted with depth or grid electrodes in order to localize the epileptogenic zone. Stereotactic depth electrodes were implanted including the following structures: amygdala, hippocampus, and frontal lobe. Ipsilateral, longitudinal depth electrodes could be kept in place during the surgery as well as contralateral depth electrodes.

To all of them ATLR was proposed. Among the patients, 3 were diagnosed with hippocampal sclerosis, which was defined as increased FLAIR signal and reduced volume on T1-weighted MRI (patients P1, P3, and P10).

As described in the Results section, IEDRs were successfully monitored in 69.2% (9/13) of patients with depth recordings and only in 4.8% (1/21) of patients with temporal scalp recordings. The mean age at surgery of patients with successful recordings was 32.6 years (standard deviation, SD: 13.5) and at epilepsy onset 15.4 years (SD: 7.8; Table 1; 7 male, 3 female). Regarding seizure type, 8 patients suffered from complex partial seizure only, 2 from secondary generalized seizure.

Two patients received amygdalohippocampal deep brain stimulation until surgery was programmed (P4, P5), with moderate-to-poor improvements in seizure rates [25]. ATLR was decided as an option consequently to this lack of results. In the case of patient P4, subsequent preoperative electrical source imaging performed with high-resolution interictal EEG (256 channels, distributed linear inverse solution) allowed us to localize an interictal epileptic focus at the anterior part of the temporal lobe [26].

The research was conducted according to the recommended ethical guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of the University Hospitals of Geneva (CER 11-088).

IEDR and Statistics

EEGs were sampled at 5 kHz (BrainAmp MR plus, Brain Products GmbH, Munich, Germany). IEDRs were computed from EEG of intracranial depth electrodes located contralaterally into the amygdala or hippocampus, or longitudinally into the hippocampus on the surgery side (Ad-Tech Instruments, Racine, WI, USA), or from temporal and ipsilateral scalp electrodes (DME1001, Medtronic Xomed Inc., Jacksonville, FL, USA).

Before IEDRs were computed, burst suppression stages were detected: they were defined as the occurrence of 2 consecutive sliding EEG windows of amplitude, peak to peak, lower than 35 μ V (0.5 s duration with sliding steps of 0.1 s [27]). If at least 1 burst

Table 1. Preoperative characteristics of patients

Pa- tient	Age/ age at onset	Gender/ domi- nance	Preop. (seizure type/ seizure freq.)	Preop. AED, mg	MRI	Interictal EEG		Ictal EEG		IAT site alteration	Psychiatric evaluation
						noninvasive	invasive	noninvasive	invasive		
Patients with depth electrodes											
P1	44/14	M/R	CPS (4/d; 2/y)	LEV 250	R HS	R Sph > L Sph	R Ant T > L T	R T > L T	R Hipp	NP	N
P2	21/13	M/R	CPS (3/d; 1/w)	OXC 300-0-600	N	L Sph > R Sph	L Ant T > R T	R Ant T	Neocortical T	NP	N
P4	51/4	F/R	CPS (5–6/m)	OXC 600-0-600 MDL 500-0-250	N	R T > L T		R T > L T		L Hipp Vis Mem Def	D
P5	35/15	M/R	CPS (7/m)	LEV 1,000-0-1,000	N		L Hipp > R		L Hipp > R	L Hipp Verb Mem Def	A
P6	49/33	M/Am	CPS (1–2/m)	CBZ 200-0-400 LCM 100-0-100	Asymmetric mammillary body; L < R	L T	L Lat polar T	L T	L T polar	NC	N
P7	13/11 m	M/R	CPS (2/d) SecGS (2/y)	LTG 150-0-150 VPA 450-0-450 CBZ 1-0-100 CLB 0-0-10	Multiple tubers; white matter abnormalities cerebellar arachnoid cyst	L Fr T	L Post T basal	L T > hemisphere	L Ant T basal	NP	NP
P8	27/23	M/R	CPS (1–2/m)	CBZ 600-0-600 VPA 500-0-500	N	L Fr T > R	L T	L T polar, basal, L Hipp	L Hipp	NP	Hyper- activity
P9	26/13	F/R	CPS (15/m) SecGS (2–3/m)	CLB 15-10-15 CBZ 600-0-800	N	L T > R T	L Ant T, L Hipp	–	L Ant T, Hipp > L Lat	NC	D
P10	42/17	F/L	CPS (1/w)	LTG 200-0-200 PRM 125-0-125	L HS; L Lat abnormality T	L T > R T	L T > R T	L T > R T	L T > R T	NP	D
Patient with scalp electrodes											
P3	18/11	M/R	CPS (1/d)	CBZ 600-0-600	R HS	R Ant T > R Fr T	R Ant T > R Fr T > L T	R T	R A → R Hipp	NP	N
Age at implantation in years; age at epilepsy onset in years; gender: female (F), male (M); dominance: ambidextrous (Am), left (L), right (R); seizure types: complex partial seizure (CPS), secondary generalized seizure (SecGS); range of seizure frequency: per year (/y), per month (/m), per week (/w), per day (/d); antiepileptic drugs (AEDs): carbamazepine (CBZ), lacosamide (LCM), clobazam (CLB), levetiracetam (LEV), lamotrigine (LTG), midazolam (MDL), oxcarbazepine (OXC), valproate (VPA), primidone (PRM); MRI: normal (N), hippocampus sclerosis (HS); localization of interictal and ictal EEG abnormalities: amygdala (A), hippocampus (Hipp), frontal or fronto- (Fr), lateral or latero- (Lat), anterior (Ant), sphenoidal (Sph), posterior (Post), temporal (T); intra-arterial amobarbital test (IAT): not performed (NP), not contributive (NC), deficit (Def), memory (Mem), visual (Vis), verbal (Verb); psychiatric evaluation: anxiety (A), depression (D).											

Age at implantation in years; age at epilepsy onset in years; gender: female (F), male (M); dominance: ambidextrous (Am), left (L), right (R); seizure types: complex partial seizure (CPS), secondary generalized seizure (SecGS); range of seizure frequency: per year (/y), per month (/m), per week (/w), per day (/d); antiepileptic drugs (AEDs): carbamazepine (CBZ), lacosamide (LCM), clobazam (LEV), levetiracetam (LEV), lamotrigine (LTG), midazolam (MDL), oxcarbazepine (OXC), valproate (VPA), primidone (PRM); MRI: normal (N), hippocampus sclerosis (HS); localization of interictal and ictal EEG abnormalities: amygdala (A), hippocampus (Hipp), frontal or fronto-lateral or latero-lateral (Lat), anterior (Ant), sphenoidal (Sph), posterior (Post), temporal (T); intra-arterial amobarbital test (IAT): not performed (NP), not contributive (NC), deficit (Def), memory (Mem), visual (Vis), verbal (Verb); psychiatric evaluation: anxiety (A), depression (D).

suppression period was detected per minute, then the IEDR for that particular minute was discarded. The burst suppressions detected were verified visually (BESA, MEGIS Software GmbH, Germany).

An automated continuous IED detector was applied as previously described [12]. It computed the number of IEDs per minute (IEDR per se; Matlab, Mathworks, Natick, MA, USA). Its algorithm combines wavelet transform and basic detection theory [28]. A bayesian hypothesis test is applied to the putative IED in order to take into account the scarcity of these events into the EEG. Multiple discharges occurring within 300 ms were merged and associated with a single event. Hence detected spikes were equivalent to the so-called isolated discharges and to the continuous discharges described by Oliveira et al. [19].

This method was first described and compared to IED marked by expert neurologists within the framework of 1 previous deep brain stimulation study [12]. Since the recording conditions of an operating room are different from the ones of this previous study, the comparison to human EEG marking was conducted again: IEDs were marked by our EEG experts in 4 samples of 10 min each. The samples were taken from recordings performed in 2 patients, P1 and P2: 1 sample prior to and 1 sample after resection for both patients. The sensitivities of automated IEDs were: for patient P1, 68.9 and 79.6%; for patient P2, 84.4 and 77.5% (before and after resection, respectively). Using the same golden rule, i.e. IEDs marked by at least 2 of the 3 EEG experts are retained, the detector achieved a performance comparable to that of the EEG specialists with a combined sensitivity of 76% (event frequency and recording length weighted [29]). This result is equivalent to that previously described [30] (73.9%). Additionally, our 3 neurophysiologists were individually evaluated, each according to their own markings, by applying the same aforementioned rule: they achieved sensitivities of 55.2% (less experimented), 80.3% (experimented) and 98.8% (most experimented neurophysiologist), in agreement with their professional experience. Hence, the automated IED detector performed as well as experimented neurophysiologists in this comparison while it was disfavored because not considered being within the golden rule.

EEGs were again submitted to visual inspection to discard remaining artifacts not detected by the automated artifact rejection [12], e.g., artifacts from the radiofrequency cut or blend systems.

The changes in IEDR medians were assessed by a Wilcoxon rank sum test. The IEDRs computed up to the beginning of the resection were compared to the IEDRs computed between the beginning and the end of the ATLR. The IEDRs computed 10 min before the resection of the mesial structures were compared to those computed 10 min after that last resection when performed.

The difference between proportions of successful monitoring performed with depth versus scalp electrodes was examined with z -tests and was accepted as significant with a 1% risk (i.e., $p < 0.01$).

Anesthesia Protocol

Antiepileptic drugs were not interrupted before surgery. Anesthesia was conducted using target controlled infusion (Base Primea, Fresenius-Vial, Brezins, France) of propofol [31, 32] and sufentanil [33, 34]. For induction, concentrations were for propofol 4.5–5.0 $\mu\text{g/mL}$ and for sufentanil 0.3–0.4 ng/mL . During maintenance these concentrations were carefully monitored and kept constant, and burst suppression was avoided (Table 2).

Resective Surgery

In all cases, the surgery was planned according to the patient's presurgical evaluation and was not modified according to the changes in IEDRs during the surgery. In the operating room, coregistration of the head surface and the preoperative MRI was performed with a neuronavigation system (Stealthstation, Medtronic, Minneapolis, MN, USA). Consequently, the head was rotated approximately 45° to the opposite side and in slight hyperextension.

Approximately a length of 3.5 cm was measured from the pole along T1, which was considered as being the posterior limit of the temporal polectomy. T1 was first resected subpially to the pole and hence towards the uncus. The temporal lobe was then transected transversally from T1 and the anteroinferior border of the insula down to the collateral sulcus, allowing the lateral temporal pole to be removed on bloc: it allowed then the proper identification of the temporal horn and the temporomesial structures. When an amygdectomy was performed, the amygdala was resected up to the optic tract. In case of hippocampectomy, the hippocampus was removed from the choroidal fissure superomedially to the collateral eminence inferolaterally, and as posteriorly as possible. The adjacent uncus and parahippocampal gyrus were aspirated.

Long-Term Outcome

Postoperative outcome was evaluated 12 months after the surgery. Effects of surgery on the seizure occurrences and types were assessed by using the International League against Epilepsy scale [35]. This is a 6-class scale, with classes 1–4 covering absence of seizures to significant seizure reduction and classes 5 and 6 including nonsignificant reduction and an increase in seizure frequency (International League against Epilepsy scores 1–6). Possible changes in antiepileptic drugs were monitored.

Results

EEGs were recorded in 38.2% (13/34) of patients from depth and in 61.8% (21/34) from scalp electrodes only. Too low IEDRs, i.e., lower than 5 at the beginning of the surgery, precluded the monitoring in 38.0% (8/21) of patients with scalp electrodes. The occurrence of burst suppression precluded the monitoring in 30.8% (4/13) of patients with depth electrodes and in 57.1% (12/21) of patients with scalp electrodes.

The IEDR monitoring was achieved in 10 patients, i.e., 69.2% (9/13) of depth and 4.8% (1/21) of temporal scalp recordings. The proportion of successful IEDR monitoring was significantly higher when performed with depth than with scalp electrodes ($z = 3.72$, $p < 0.001$). The contributive depth electrodes were located longitudinally into the hippocampus on the surgery side (5/9 patients) or contralaterally into the amygdala or hippocampus (4/9 patients; Table 2).

Within the group of 10 patients with successful IEDR monitoring, ATLRs were performed in conjunction with

Table 2. Surgical and postsurgical characteristics of patients

Resection			Seizure frequency 1 year after surgery	ILAE	Long-term AED	Mood	Long-term EEG	Anesthetic		Recording sites
side	site							propofol, µg/mL	sufentanil, ng/mL	
<i>Patients with depth electrodes</i>										
P1	R Ant	Am Hipp	SF	1	Free for last 6 m	Constant improvement	R T slowing	U	U	Contra Am
P2	L Ant		SF		OXC 300-0-300	Fragility	N	U	U	Contra Hipp
P4	R Ant		SF	1	OXC 600-0-600 LEV 1,000-0-100	N	Scarce Fr interictal discharges	4.0±2	0.2	Ipsi Hipp (DBS electrode)
P5	L Ant	Am	CPS (7/m)	5	LEV 1,000-0-1,000 LCM 100-0-200	A	NP	U	U	Ipsi Hipp (DBS electrode)
P6	L Ant		SF	1	CBZ 200-0-400 PGB 100-0-100 CLB 5-0-5	N	L T slowing	4.5	0.2	Ipsi Hipp
P7	L Ant	Am Hipp	SF	1	CBZ 200-0-200	NP	NP	4	0.25	Ipsi Hipp
P8	L Ant	Am Hipp	SF	1	CBZ 600-0-600 VPA 500-0-500	N	NP	4.5	0.1	Ipsi Hipp
P9	L Ant	Am Hipp	SF	1	CBZ 600-0-400	NP	N	4.5	0.15	Ipsi Hipp
P10	L Ant	Am Hipp	CPS (2/y)	3	LTG 200-0-200 PRM 125-0-125	D	N	U	U	Contra Hipp
<i>Patient with scalp electrodes</i>										
P3	R Ant	Am Hipp	SF	1	At 36 m: 0-0-0 At 24 m: CBZ 200-0-200	N	R T slowing	Isoflurane	sufentanil 0.25 ng/mL	Ipsi T

Localization of resection: left (L), right (R), anterior temporal lobe (Ant), amygdala (Am), hippocampus (Hipp); seizure types: complex partial seizure (CPS), seizure free (SF), per month (/m), per year (/y); seizure occurrences using the International League against Epilepsy scale (ILAE); antiepileptic drugs (AED): oxcarbazepine (OXC), carbamazepine (CBZ), clobazam (CLB), levetiracetam (LEV), pregabalin (PGB), lamotrigine (LTG), primidone (PRM); mood: normal (N), anxiety (A), depression (D), not performed (NP); long-term EEG: temporal (T), frontal (Fr); anesthetic dosages: unknown (U); recording sites: contralateral depth electrode (Contra); ipsilateral depth electrode (Ipsi), ipsilateral scalp electrodes (Ipsi T).

amygdalohippocampectomy in 60.0% (6/10), with amygdalectomy in 10.0% (1/10) of patients and without mesial structure resection in 30.0% (3/10) of patients with successful IEDR monitoring (Table 2).

The IEDRs computed successfully all along the surgical procedures are described in Figure 1 for the depth recordings and in Figure 2 for the single contributive scalp recording. A significant decrease in IEDRs was observed in 80.0% (8/10) of patients once the ATLR was performed ($p < 0.001$). These decreases started with the resection of the superior temporal gyrus and continued with the posterior section of gyri T1, T2, T3, and T4, taking place before the section of the temporal stem and the “en bloc” removal of the lateral temporal pole. They were observed ipsilaterally or contralaterally. This is expectable as contralateral invasive exploration was performed in these patients to exclude a bilateral epileptic focus suspected because of bilateral epileptiform activity. This observation indicates an immediate effect of the ATLR of the primary epileptic focus that has an immediate effect on the contralateral mesial structures. Within these 8 patients with

significant decreases, 1 patient underwent – in addition to ATLR – resection of the amygdala, and 5 patients amygdalohippocampal resection. In 1 of these patients, only scalp recordings were performed, preventing the measurements of possible subsequent decreases in IEDRs, as IEDs were not observed anymore from scalp recordings once ATLR had been performed. Subsequent decreases, beyond ATLR, were observed with mesial structure resection in 60% (3/5) of patients with depth recordings.

IEDR decreases could be interrupted by temporary recrudescence of IEDs observed at the time of hippocampectomy (e.g., P3, P7, P9). This could be due to a new deafferentation. Patient P5 presented very numerous bilateral hippocampal spikes. In his case, the absence of IEDR decrease and seizure reduction suggested a right TLE focus.

At the 12-month follow-up, 100% (8/8) of patients with significant IEDR decreases remained seizure free after ATLR with mesial structure resection; both patients without IEDR decreases had still seizures (P5, P10). The

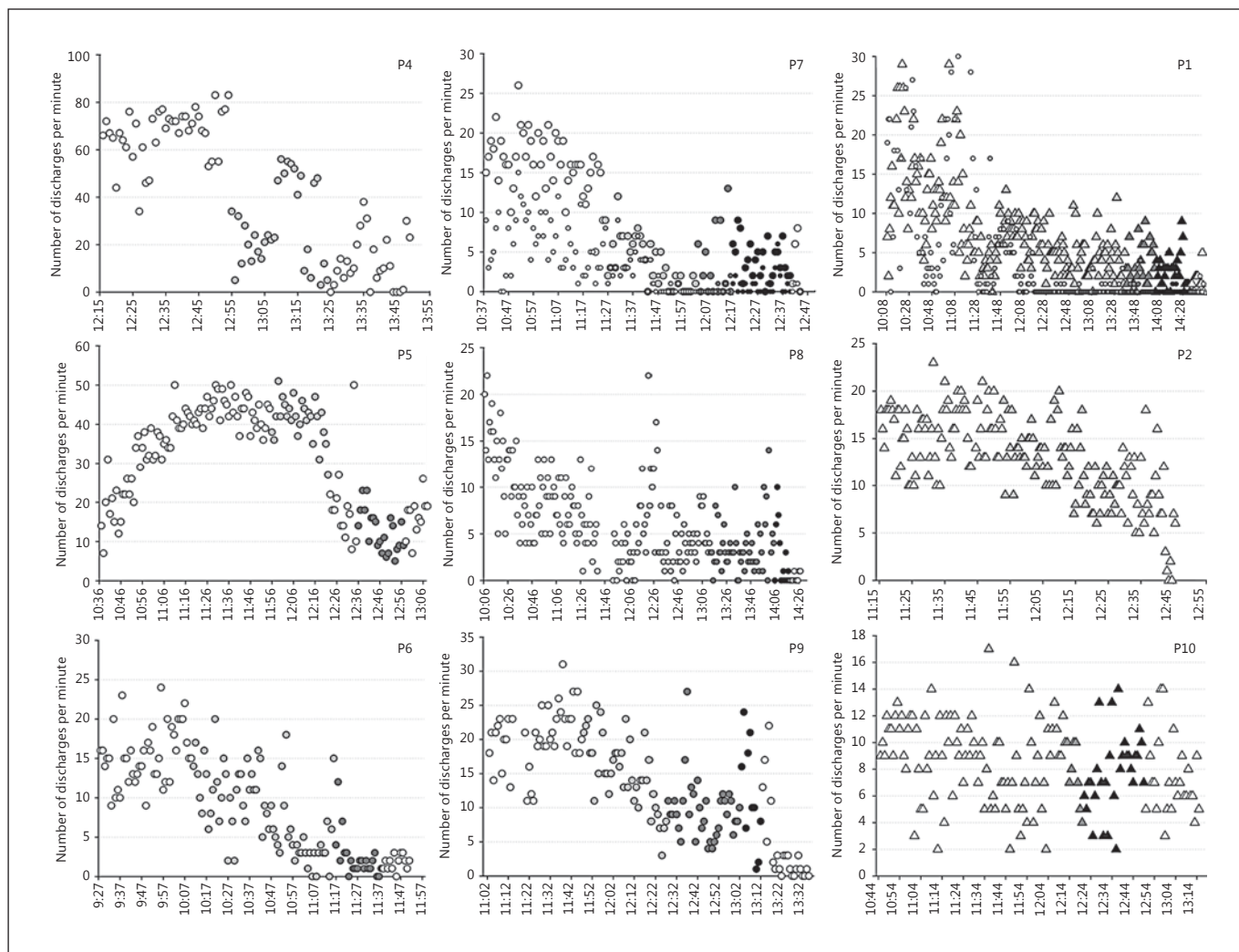


Fig. 1. Each graph describes the IEDR monitoring of a single patient recorded from depth electrodes all along the surgery. On the ordinate: number of interictal epileptiform discharges per minute (IEDR); on the abscissa: time; ○, ipsilateral recording; △, contralateral recording; white symbols, before beginning of resection; light gray, during ATLR; dark gray, during uncus and amygdala resections; black, hippocampectomy.

positive and negative predictive values of intraoperative IEDR changes on seizure occurrence were 100% at the 12-month follow-up.

Discussion

The IEDR monitoring was successful in the patients recorded with depth electrodes but it was merely not possible in patients recorded with scalp electrodes. Its feasibility relies on the absence of EEG burst suppressions and on a minimum number of IEDs per minute.

This study shows that intraoperative and continuous monitoring of IEDRs can be performed with depth electrodes to describe the effects of the surgery on the principal neurophysiological marker of TLE. The observation of a significant decrease in IEDRs was observed in all seizure patients evaluated 1 year after the surgery. In all cases this decrease started with the resection of the superior temporal gyrus, terminating with the posterior section of temporal gyri. This decrease continued further with mesial structure resection in only a subpopulation of the group of patients.

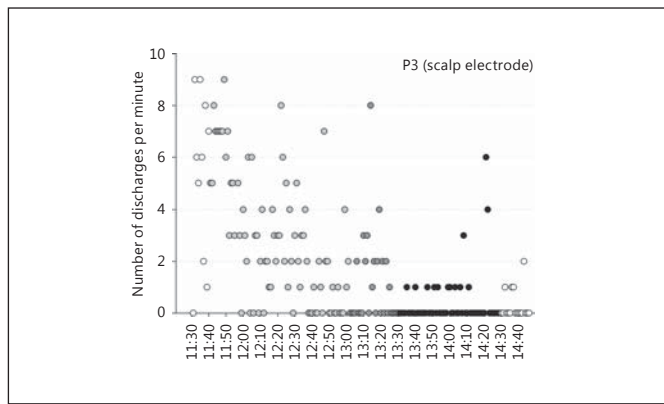


Fig. 2. IEDR monitoring in the single patient with recordings from contributive scalp electrodes all along the surgery. On the ordinate: number of interictal epileptiform discharges per minute (IEDR); on the abscissa: time; white symbols, before beginning of resection; light gray, during ATLR; dark gray, during uncus and amygdala resections; black, during hippocampectomy.

Temporal Lobe Surgery

The significant decrease in IEDRs observed in all seizure-free patients at the time of ATLR, before the mesial structure resection when performed, advocates a key role of ATLR in TLE. This is particularly true when a localized neocortical epileptic focus is found. This alleged key role of ATL is reinforced by the observation that polectomy with mesial structure resection has been shown to be more efficient than selective amygdalohippocampectomy (SAH) alone [36]. This is in agreement with prior statements suggesting that “the pole was implicated early in the onset of epilepsy” [37, 38]. In this sense, Thom et al. [39] observed a disorganization of the temporopolar cortex in TLE with hippocampal sclerosis, suggesting an anterior-mesial progression of an acquired pathology.

Subsequent decreases, beyond those produced by ATLR, could be observed with mesial structure resection, supporting also the important role of mesial structures in some TLE. Conversely to Sindou et al. [36], SAH was also shown to be as efficient as mesial ATLR [40]. Different surgical methods (“center effect”) can explain the fact that SAH is reported as less efficient than mesial ATLR [41]. A concomitant collateral lesion of the ATL is also present when SAH is performed, either by transsylvian (entrance through “the temporal stem in the inferior circular sulcus”) or transcortical approaches [1]. As Schramm and Clusmann [1] underlined, the only method that did not seem to be as efficient as ATLR in suppressing seizures was the stereotactic ablation, which did not injure the

entorhinal cortex. The role of the entorhinal and perirhinal cortices in TLE has been recently further underlined [42].

These observations altogether make us question what part of resections, which extinguishes a possible anterior temporal lobe epileptiform focus, is common to ATLR, performed with or without mesial structures, and to SAH. In all procedures, (1) the temporal stem is sectioned, altering the temporal network which sustains the epileptic process, and (2) the entorhinal cortex is either resected or isolated from the temporal network.

Predictive Values of IEDR

In this series of patients, a significant decrease in IEDRs observed with the ATLR could be used as a predictive neurophysiological marker of surgical success in terms of seizure occurrence (100% positive and negative predictive values at a 1-year follow-up). Conversely, the presence of residual or new spikes does not predict seizure outcome in TLE [30, 43–45]. The current study may have been successful in predicting seizure outcome because it considers the whole surgery and thus accounts for a general tendency. As mentioned above, Oliveira et al. [19], comparing intraoperatively IEDs before and after resection of the temporal pole and after resection of the mesial structures, concluded that the observation of isolated postresection discharges was the only variable predictive of patient outcome. The present study, continuously and automatically analyzing IEDRs along the entire surgery, confirms this first observation. Hence, intraoperative monitoring of IEDRs appears to be an indirect measure of ATLR success, therefore showing its potential value as another evaluation modality in epilepsy surgery, in addition to more renowned and well-established techniques such as intraoperative electrocorticography [46–49].

In the future if no IEDR drop is observed during ATLR, the relevance of mesial structure resection in nonlesional cases could be reevaluated before amygdalohippocampectomy is performed, in particular in cases of bilateral TLE, or in cases of other extratemporal lesions. A larger cohort of patients could confirm this statement.

Limitations of IEDR Monitoring

The principal limitation of the continuous IEDR monitoring was that of the anesthesia which should avoid EEG burst suppression [50]. All patients received targeted controlled infusions of propofol and sufentanil. To avoid the periods of burst suppression, the Bispectral Index™ may be employed. Unfortunately this was not the case in all recorded patients at the time of the study.

The other limitation of the IEDR monitoring was the need for a consequent number of IEDs per minute at the beginning of the surgery, in order to be able to assess its changes (i.e., >5/min). Hence, so far, not all ATLRs can be monitored with IEDRs; in this sense, patients presenting with longer disease duration might be more frequently eligible [23].

Continuous monitoring with IEDR was possible with depth electrodes but not merely with scalp electrodes. The rates of IEDs were certainly limited with scalp recordings because of their distant localization from the temporal cortex and from the impedance of the skull. In particular, IEDs generated in mesial structures were not recorded correctly from subdermal scalp electrodes, as illustrated by patient P3 and as discussed by Wennberg et al. [35]. The indication of positioning 1 depth temporal lobe electrode before the resection starts, when none are available from the invasive preoperative exploration or when this exploration was not performed, could be valuable in verifying the efficiency of the resection intraoperatively.

Conclusion

The continuous IEDR monitoring of ATLR was possible from depth but not from scalp electrodes when adequate anesthesia was performed (i.e., no burst suppression). The resection of the superior temporal gyrus already decreased the IEDRs that could or not decrease further with the amygdalohippocampectomy. IEDR monitoring was fully reliable in predicting the success of surgery as evaluated 1 year after surgery. Larger cohorts of patients are required to verify whether IEDR monitoring can be used as a marker of successful surgery, and possibly as a tool for tailoring this surgery.

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